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Part I: Performance Enhancement Methodology of Flat-Plate Photovoltaic-Thermal (PVT) Air Collector Systems

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Abstract: PhotoVoltaic Thermal (PVT) solar collectors are hybrid collectors that are able to generate simultaneous thermal and electrical energy. Various developmental methods are available in the literatures on the performance enhancement of these hybrid collectors. The designs have been studied and compared in this research in order to adopt the best method for the future experimental study. The Compound Parabolic Concentrators (CPCs) and fresnel lens were chosen as concentrators to be adopted in the experimental research due to the ability to increase in incident radiation intensity and uniformity of light distribution on the solar cells. Furthermore, the double pass air flow channels were selected for heat extraction due to the possible high PV plate temperature profile owing to the double concentrators.

Key words: Designs, experiment, methodology, photovoltaic, solar collectors, distribution

INTRODUCTION

The PVT technology has been studied, since, the early 1970's (Wolf, 1976). Since, then, this technology has gained attention among researchers and its efficiency has increased. The studies have ranged from mathematical simulations (Gao *et al*., 2000; Florschuetz, 1979) to experimental studies and computer simulations. Water and air are the common working fluids of the PVT system. A low-cost method of using air as heat extracting fluid to maintain the PV plate temperature whereby the exhausted air is utilized for other purposes (Tonui and Tripanagnostopoulos, 2007). In the study, performance comparison between glazed and unglazed PVT air collector showed that the glazed collector yielded lower electric efficiency but higher thermal efficiency. The higher thermal efficiency achieved was due to the higher amount of heat trapped between the glaze (cover) and absorber which consequently reduced the electrical output of the PV plate. An experimental study of an air-based PVT collector was carried out and validated by a numerical model (Sarhaddi *et al*., 2010). Whereby when the air speed was increased from 0-10 m/sec, the electrical efficiency increased by 1.5%. However, the overall energy and thermal efficiencies decreased approximately 10%. This is because higher air speed increased the overall heat loss coefficient which then reduced the PV temperature and hence higher electrical efficiency.

AIR FLOW CHANNEL ENHANCEMENT

Channels for air flow are also important factors to be considered in a PVT collector design. Most studies focused on the single-pass design whereby air flows in from one end and exits the collector from the other end (Alfegi *et al*., 2008). The channels were also enhanced with honeycomb and rectangular heat exchangers in order to improve the heat transfer coefficients (Jin *et al*., 2010). The air channels were further improved by using double-pass configurations (Othman *et al*., 2005; Sopian *et al*., 2002; Othman *et al*., 2007). The double-pass PVT collector developed by Sopian *et al*. (2002) has shown a 50-60% of thermal efficiency while maintaining the electrical efficiency at approximately 10%. The channel's surface area was also be further enhanced by the additional fins at the back of the absorber plate (Fudholi *et al*., 2013; Kumar and Rosen, 2011; Elsafi and Gandhidasan, 2015). Fins increased the surface area and turbulence for the heat convection by the working fluids. Table 1 shows some types of PVT air collectors previously studied and their performance enhancement methods. Othman *et al*. (2005) has utilized the double pass air flow configuration with the Combination of Concentrators (CPC) and fins in their design. Their study showed that the designed configuration has potential to provide a significant increase in power production and reduce the cost of PV electricity.

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Table 1: Type of enhancement and performance efficiency of previously studied PVT air collectors

Researchers	Type of collector	Type of enhancement	Collector area (m^2)	Thermal efficiency (%)	Electrical efficiency (%)
Joshi and Tiwari (2007)	PVT air collector	Single pass	0.610	48.0-60.0	12.0
Sopian *et al.* (2002)	PVT air collector	Double pass	0.974	50.0-60.0	~10.0
Othman *et al.* (2013)	PVT air collector	Double pass	-	32.0-85.0	6.9-7.2
Kim *et al.* (2014)	PVT air collector	Single pass	1.600	~ 22.0	9.0-17.0
Sohel *et al.* (2014)	PVT air collector	Single pass	-	10.0-55.0	~7.0
Kunnemeyer *et al.* (2014)	PVT air collector	V-through	-	~ 31.0	-

CONCENTRATING COMPONENT ENHANCEMENT

Moreover, the thermal behaviour of PVT collectors can be further improved through the applications of concentrators such as Compound Parabolic Concentrators (CPC), Parabolic Troughs (PT) (Calise and Vanoli, 2012) or Fresnel Lens (FL). The addition of CPC to a PVT system able to improve the light distribution that incident on the solar cells to produce a stable electric current (Ustaoglu *et al.*, 2016). The first design of CPC was introduced in Winston (1974). The varieties of 2D CPCs regarding their general characteristics such as concentration ratio, acceptance angle, sensitivity to mirror errors, the size of the reflector area and an average number of reflections are compared by Rabl (1976). Installation of CPC was able to double the solar irradiation 2000 W/m^2 and the electrical output (11%) of the PV plate (Ceylan *et al.*, 2016). PVT collector integrated with CPC and fins for heat transfer enhancement has shown increments in both thermal and electrical performance (Othman *et al.*, 2005). The study showed that the addition of CPC improved the thermal efficiency by approximately 10% while due to Infrared (IR) Radiation effect, the electrical efficiency dropped approximately half. The PVT air collector integrated with CPC is as shown in Fig. 1.

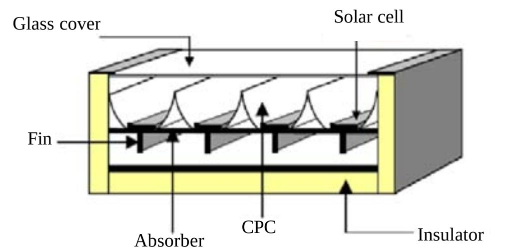

Fig. 1: PVT air collector with CPC (Alfegi *et al.*, 2008)

Fresnel lens was introduced as a concentrator which uses the principle of refraction of light. A thorough review of the recent development of Fresnel lens concentrating systems has been provided by Xie *et al.* (2011). The use of Fresnel lenses are dominant in solar thermal systems (Kumar *et al.*, 2015; Zhai *et al.*, 2010; Lin *et al.*, 2014). Some other researches have focused on concentrating PV systems using FL such as by Sonneveld *et al.* (2011) and Wu *et al.* (2012). Few researches have focused on concentrating PVT systems by integrating Fresnel lens into the design. High temperature produced due to the concentrated light with Fresnel lens is one of the reasons for the lack of interest. A static Fresnel concentrator combined with a photovoltaic solar collector was developed by Chemisana *et al.* (2011). The system reduced the solar cell required area which then reduced the cost of the system. Moreover, the heat collected from a concentrated PVT systems was also able to be used for other purposes such as cooling in refrigeration, desalination and steam production (Mittelman *et al.*, 2007). The Fresnel lens integrated PV collector is as shown in Fig. 2.

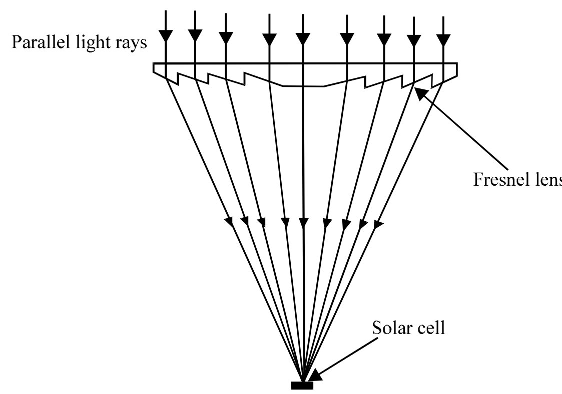

Fig. 2: Schematic of a Fresnel lens PV concentrator (Ryu *et al.*, 2006)

CURRENT PVT AIR COLLECTOR SYSTEM DESIGN

In this study, a hybrid flat plate PVT collector that combines Fresnel lens as a primary concentrator and CPC as a secondary concentrator (cPVT) was fabricated. It was a fan assisted system whereby air was used as the working fluid and a double-pass airflow configuration was designed to increase the convective heat transfer and also to provide a large surface area for convection.

Upon comparison with research by Sopian *et al.* (2002) and Fudholi *et al.* (2013) the current PVT collector system will be fabricated as shown in Fig. 3. The double pass configuration for the air to flow is adopted due to the larger convection surface area and high output air outlet temperature. Furthermore, the utilization of CPCs and

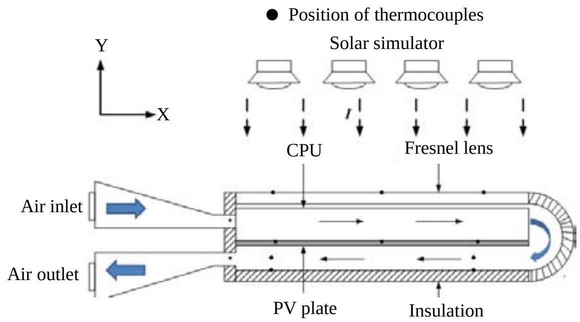

Fig. 3: Schematic of the concentrating PVT collector with Fresnel lens and CPC

Table 2: Specification and dimensions of the current study PVT air collector

Specification	Values
Collector length	0.82 m
Collector width	0.64 m
Upper channel depth	0.17 m
Lower channel depth	0.07 m
Absorber length	0.65 m
Absorber width	0.60 m
Absorber thickness	0.002 m
Fresnel lens length	0.77 m
Fresnel lens thickness	0.003 m
$CR_{Fresnel}$	1.65
CR_{CPC}	1.78
Air blower	45 W power
Temperature sensors	K-type thermocouples
Airflow meter	Hot-wire anemometer

Fresnel lens as an addition to the improvement of the thermal performance has been adopted inspired from (Alfegi *et al*., 2006; Jin *et al*., 2010; Ceylan *et al*., 2016). The Fresnel lens used in this study is made out of glass because of its higher durability compared to PMMA acrylic type (Miller and Kurtz, 2011). The specifications and dimensions of the concentrating PVT air collector developed is as listed in Table 2. The size of the collector fabricated is smaller which reduced the cost of the expensive solar cells required for the PV panel. The system also do not require an additional tracking system with the use of CPCs as reflectors.

CONCLUSION

The current study is divided into two parts. This study covers part 1 in which the literature and background research have been conducted by considering designs and methodologies of PVT air collectors carried out by previous researchers. Through the study, the most suitable collector designs and components required for the fabrication of the concentrating PVT air collector for the current study are chosen. Two types of concentrators were chosen namely Fresnel lens and CPCs. The double pass air flow channel are chosen over the single pass due to its higher surface area for convection due to the high temperature produced by the dual concentrators. The experimental results and observations are discussed in part 2 of this study.

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